(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 293 049 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication of patent specification: **29.09.93** (51) Int. Cl.5: **G01S 3/78**

(21) Application number: **88201029.1**

(22) Date of filing: **20.05.88**

(54) **A light detecting and light direction determining device.**

(30) Priority: **27.05.87 SE 8702245**

(43) Date of publication of application:
30.11.88 Bulletin 88/48

(45) Publication of the grant of the patent:
29.09.93 Bulletin 93/39

(84) Designated Contracting States:
DE FR GB IT NL SE

(56) References cited:
EP-A- 0 082 045
GB-A- 2 112 244
US-A- 4 625 108

(73) Proprietor: **NobelTech Systems Aktiebolag**

S-175 88 Järfälla(SE)

(72) Inventor: **Biverot, Hans Gunnar**
c/o INT. OCTROOIBUREAU B.V. Prof. Holstlaan 6
NL-5656 AA Eindhoven(NL)

(74) Representative: **Falk, Bengt**
Swedish Ordnance Patents and Trademarks
S-691 80 Karlskoga (SE)

EP 0 293 049 B1

Description

The invention relates to a light detecting and light direction determining device comprising a plurality of light receiving elements, said light receiving elements being divided into at least two groups having different sensitivity directions, each group containing a plurality of light receiving elements, a respective light combining device assigned to each group and to which said light receiving elements of each said group are optically coupled, each said light combining device combining the light received from its respective light receiving elements, and a comparator to which said light combining devices are coupled, which compares the output signal of the light combining devices for determining the direction of the wave front of the incident light.

The term light is herein understood to mean ultraviolet and infrared radiation as well as visible light, which radiation is orginally coherent, that is to say, the wave front from the light source has a high degree of correlation in time and space, which is the case for laser light.

A light detecting and direction determining device of the type described above is inter alia known from GB-A-2 112 244. The light receiving elements are here formed by one of the end surfaces of optical fibres (light guides). Each end surface of a fibre, which serves as a receiving element, normally covers a separate angular space while each fibre has a different length which is used to identify the angular space in question. The receiving elements may be divided into a plurality of groups. During real operation conditions affected by air turbulence and so called "speckles" associated herewith, a device of the type described above has an insufficient performance, especially in the case of separate laser pulses.

The object of the invention is to obtain a light detecting and direction determining device which can cope with these real operating conditions. This is obtained by means of a device according to the invention which detects the wave front of the incident light in such a way that a statistically more favourable distribution is obtained and which thereby increases the chances of discovering the light and determing its direction. The statistically more favourable distribution situation will be explained in more detail below. To achieve the object of the invention the light detecting and direction determining device according to the invention is characterized in that the light receiving elements within each of said groups have a coincident sensitivity direction and are spatially separated from each other by a distance of at least $(XR)^{1/2}$, where X is the wavelength of said light and R is the distance between the source of said light and said light receiving elements.

The correlation of the light distributed by the influence of the atmosphere, i e air turbulence, which causes irregularities to arise in the wave field is complicated and has been described inter alia by V.I. Tatarski. "Wave propagation in Turbulent Medium" (Mc Graw-Hill, New York, 1961) and by J.W.Goodman, "Statistical Optics" (John Wiley 1985). The amplitude statistics of the wave field at a point maybe described by means of logarithm-normal distributions. When the turbulence of the air has high values, which is commonly expressed by means of the variance of the logarithm for the irradiance of the wave field, var (1n H), a saturation condition occurs having a one-sigma distribution of 1n(H) close to 2. The irradiated area is divided into smaller (connected) parts so called W "speckles" having geometrical dimensions of the order of magnitude of a Fresnel radius, that is $(XR)^{1/2}$, in which X is the wave length and R is the distance between the light source and the light receiving element. Within each area having such dimensions (an elementary area in the phase space having an extension in time which depends on coherence and an extension in size which depends on the so-called spatial coherence), there is a high correlation between the parts of the field, while the correlation is low at greater distances.

The statistical distribution of the light wave field in one point, when having passed through a turbulent atmosphere, shows a very pronounced skewness having a high concentration of the frequency function towards the origin. This means that the signal-to-noise ratios required for a high detection probability of separate laser pulses within surfaces having an extension less than the Fresnel radius are very high. The known device as described above therefore requires a very large signal-to-noise ratio to be able to detect separate laser pulses with great probability.

If instead, as is the case according to the invention, the light detecting and direction determining device comprises light receiving elements which sample the wave field from a number of receiving surfaces having a mutual distance apart of the order of magnitude of at least the Fresnel radius i.e. the decorrelation distance, the skewed concentration of the frequency function towards the origin is avoided. In fact, when the one-sigma dispersion of ln(H) is near the value of 2, the frequency function, in the case where several "speckles" are combined, shows a much more favourable appearance as regards the signal-to-noise ratio having a weak top level around the mean value of the frequency function.

The invention will be described in more detail, by way of example, with reference to the accompanying drawings, in which

Figure 1 shows a schematic embodiment of a light detecting and light direction determining device,

Figure 2 shows an example of a way of arranging the light guides in a physically delimited structure,

Figure 3 shows frequency functions of the statistical fluctuations of the wavefield when detecting in a point for $\sigma = 2$ and

Figure 4 shows the frequency function for the statistical fluctuations of the wave field when combining several "speckles".

The schematic embodiment shown in Figure 1 of a light detecting and light direction determining device according to the invention comprises two groups, each having four light receiving elements 1, 3, 5, 7 and 2, 4, 6, 8, respectively. One of the groups 1, 3, 5, 7 has a common coincident sensitivity direction 9 and the other group 2, 4, 6, 8, has another coincident sensitivity direction 10. The light receiving elements are sensitive to light in cone-shaped space around the defined sensitivity directions. Each light receiving element 1-8 is constituted by one of the end surfaces of a light conductor or a bundle of light conductors 11-18. The other end surfaces of the light guides or bundles 11, 13, 15, 17 are coupled to a first detector 19 and the other end surfaces of the light guides 12, 14, 16, 18 are connected to a second detector 20. The two detectors 19, 20 may be identical, each performing an additive combination of light intensities on the incoming corresponding light guides to generate an output signal on the respective detector circuit. It is possible to detect emitted laser pulses, if any, in the output signal with great probability. In order to determine the direction of the incident light for a laser light source, the output signal from the two detectors are compared in a comparator. A measure of the incident direction of the light is obtained, for example, by comparing the amplitudes for the output signals of the two detectors.

Figure 2 shows a simple and practical arrangement of a number of light guides in a physically delimited structure. The delimited structure has a cylindrical shape. In the inner part of the cylindrical structure a number of light guides 11-18 are introduced along the longitudinal direction of the structure. One of the end surraces of each light guide is disposed adjacent to the structure envelope while the other end surface is disposed near a detector place outside the structure in the longitudinal direction of it. Light receiving elements, that is light guide end surfaces which are arranged in a row along the longitudinal direction of the structure are included in the same group and have the same sensitivity direction. Light incident on light receiving elements belonging to the same group is combined in a common detector 19 or 20. For the sake of clearness only two groups of light receiving elements have been shown in the present embodiment. However, the proposed structure admits a great number of light receiving elements which inter alia may improve the accuracy in determining the light directions for incident laser light.

Figure 3 shows the frequency function for the statistical fluctuations of the wave field of light when detected in one single point. The frequency function is shown for $\sigma = 2$, which is a value well in accordance with reality when the light is subjected to strong turbulence. As is apparent from said frequency function, it presents a high concentration towards the origin. Around the mean value for the irradiance ($\overline{H}$) the frequency function presents a low value and there is a great risk that the light from a laser source in the shape of, for example, a separate laser pulse may remain undiscovered in the background light.

The frequency function shown in Figure 4 for the statistical fluctuations of the wave field relates to the situation when light from several "speckles" is detected. Also in this case the situation is shown for $\sigma = 2$ which is in good accordance with reality. The frequency function in this case shows a top value in the vicinity of the mean value of the irradiance ($\overline{H}$). On both sides of this top value the frequency function is slowly decreasing. Thereby the received light gets a more favourable distribution and the risk of a laser pulse, if any, disappearing in the background light is considerably less than in the case when detecting in one single point.

The light detecting and light direction determining device described above is particularly suitable as a laser warner serving to warn an object being subjected to laser light so that it is possible to employ counter measures. Another interesting field of application is optical communication. In this case the signal-to-noise ratio may be kept high by means of the sampling operation while the equipment may be designed to have small dimensions. Accordingly, an optical antenna may supplement conventional radio antennas even on mobile equipment, including portable equipment. In this case all advantages, including the selectivity, the high resistance to lapping, etc. which are significant for communication in the optical field may be used. Simultaneously the receiver gets a possibility to transmit back selectively in the correct direction which direction is detected simultaneously with the received signal.

In the above embodiment according to Figure 1, for each sensitivity direction the light is summed up on a light detector. It is also possible to utilize the fact that light passing through a light guide contains information about the angle of incidence in the light guide for light because the angle between

the direction of incidence of the laser light and the axis of the light guide is maintained to some extent. However, the azimuth direction is lost causing the occurrence of a ring of light on the output side of the light guide. The diameter of the ring in combination with interpolation of the total intensity between different groups presents information about the angle of incidence of the laser light. Information of the angle of incidence of the light may also be obtained by using the coherence of the laser light. The direction of propagation of the wave front may be detected by means of the appearance of the presented pattern when the receiver is arranged in the shape of a phase collerator, that is an optical interferometer. A laser warner which uses a so called "etalon" for this purpose has been previously proposed in US-A 4 309 108 and is designed in conventional optics and detects in one point only.

In connection with this it is also to be noted that a more check of the degree of coherence of the received light by the measuring of the visibility of interference fringes from the receiver optics is a valuable discrimination possibility for false alarm by incoherent light sources.

Claims

1. A light detecting and light direction determining device comprising a plurality of light receiving elements (1-8), said light receiving elements being divided into at least two groups having different sensitivity directions, each group containing a plurality of light receiving elements (1,3,5,7 and 2,4,6,8 resp.), a respective light combining device (20 and 19 resp.) assigned to each group and to which said light receiving elements (1,3,5,7 and 2,4,6,8 resp.) of each said group are optically coupled, each said light combining device combining the light received from its respective light receiving elements (1,3,5,7 or 2,4,6,8 resp.), and a comparator (21) to which said light combining devices (19,20) are coupled, which compares the output signal of the light combining devices (19,20) for determining the direction of the wave front of the incident light, characterized in that the light receiving elements (1,3,5,7 and 2,4,6,8 resp.) within each of said groups have a coincident sensitivity direction and are spatially separated from each other by a distance of at least $(XR)^{1/2}$, where X is the wavelength of said light and R is the distance between the source of said light and said light receiving elements (1,3,5,7 and 2,4,6,8 resp.).

2. A device as claimed in claim 1, characterized in that the light receiving elements (1-8) are formed by end surfaces of light guides or bundles of light guides (11-18) arranged for optical coupling to the respective light combining device (19,20).

3. A device as claimed in Claim 2, characterized in that said light guides (11-18) are arranged in a physically delimited structure whereby one end surface of each light guide or bundle of light guides is disposed on the envelope of the structure to operate as a light receiving element (1-8) and the other end surface is disposed outside the structure adjacent to said light combining devices (19,20)

4. A device as claimed in any of the preceding Claims, characterized in that the light incident on the light receiving elements (1,3,5,7 and 2,4,6,8 resp.) within a group is combined by adding the intensities received from each individual light guide or beam of light guides (11,13,15,17 and 12,14,18,8 resp.).

Patentansprüche

1. Vorrichtung zur Lichterfassung und -richtungsbestimmung mit einer Anzahl von Lichtempfangselementen (1-8), wobei die Lichtempfangselemente in zumindest zwei Gruppen mit unterschiedlichen Empfindlichkeitsrichtungen unterteilt sind, jede Gruppe eine Anzahl Lichtempfangselemente (1,3,5,7 bzw. 2,4,6,8) enthält, wobei jeweils eine Lichtkombinationsvorrichtung (20 bzw. 19) jeder Gruppe zugeordnet ist, mit der die Lichtempfangselemente (1,3,5,7 bzw. 2,4,6,8) jeder Gruppe optisch verbunden sind und jede Lichtkombinationsvorrichtung das von seinen entsprechenden Lichtempfangselementen (1,3,5,7 bzw. 2,4,6,8) empfangene Licht kombiniert, und mit einem Komparator (21), mit dem die Lichtkombinationsvorrichtungen (19,20) gekoppelt sind, der die Ausgangssignale der Lichtkombinationsvorrichtungen (19,20) zur Erfassung der Richtung der Wellenfront einfallenden Lichtes kombiniert, dadurch gekennzeichnet, daß die Lichtempfangselemente (1,3,5,7 bzw. 2,4,6,8) innerhalb jeder der Gruppen eine gemeinsame Empfindlichkeitsrichtung aufweisen und räumlich voneinander um einen Abstand von zumindest $(XR)^{1/2}$ getrennt sind, wobei X die Wellenlänge des Lichtes und R den Abstand zwischen der Lichtquelle und den Lichtempfangselementen (1,3,5,7 bzw. 2,4,6,8) bezeichnet.

2. Vorrichtung nach Anspruch 1, dadurch gekennzeichnet, daß die Lichtempfangselemente (1-8)

durch die Endflächen von Lichtleitern oder Bündeln von Lichtleitern (11-18) gebildet sind, die zur optischen Kopplung mit der entsprechenden Lichtkombinationsvorrichtung (19,20) angeordnet sind.

3. Vorrichtung nach Anspruch 2, dadurch gekennzeichnet, daß die Lichtleiter (11-18) in einer physikalisch beschränkten Struktur angeordnet sind, wobei eine Endfläche jedes Lichtleiters oder jedes Bündels von Lichtleitern an der Einhüllenden der Struktur angeordnet ist und als Lichtempfangselement (1-8) dient und die andere Endfläche außerhalb der Struktur angrenzend an die Lichtkombinationsvorrichtungen (19,20) angeordnet ist.

4. Vorrichtung nach einem der vorstehenden Ansprüche, dadurch gekennzeichnet, daß das auf die Lichtempfangselemente (1,3,5,7 bzw. 2,4,6,8) innerhalb einer Gruppe einfallende Licht kombiniert wird durch Addition der Intensitäten, die von den einzelnen Lichtleitern oder dem Bündel von Lichtleitern (11,13,15,17 bzw. 12,14,16,18) erhalten werden.

Revendications

1. Dispositif de détection de lumière et de détermination de direction de lumière, comprenant plusieurs éléments photorécepteurs (1-8) qui sont divisés en au moins deux groupes ayant des directions différentes de sensibilité, chaque groupe comprenant plusieurs éléments photorécepteurs (1, 3, 5, 7 et 2, 4, 6, 8), un dispositif respectif de combinaison de lumière (20 et 19) affecté à chaque groupe et auquel sont couplés optiquement les éléments photorécepteurs (1, 3, 5, 7 et 2, 4, 6, 8) de chaque groupe, chaque dispositif de combinaison de lumière combinant la lumière reçue des éléments photorécepteurs respectifs (1, 3, 5, 7 ou 2, 4, 6, 8) et un comparateur (21) auquel sont couplés les dispositifs de combinaison de lumière (19, 20) et qui compare les signaux de sortie des dispositifs de combinaison de lumière (19, 20) afin qu'il détermine la direction du front d'onde de la lumière incidente, caractérisé en ce que les éléments photorécepteurs (1, 3, 5, 7 et 2, 4, 6, 8) de chacun des groupe est ont une direction de sensibilité en coïncidence et sont séparés spatialement les uns des autres par une distance au moins égale à $(XR)^{1/2}$, X étant la longueur d'onde de la lumière et R la distance comprise entre la source de lumière et les éléments photorécepteurs (1, 3, 5, 7 et 2, 4, 6, 8).

2. Dispositif selon la revendication 1, caractérisé en ce que les éléments photorécepteurs (1, 8) sont formés par des surfaces d'extrémité des guides de lumière ou des faisceaux de guides de lumière (11-18) destinés à assurer le couplage optique avec le dispositif respectif de combinaison de lumière (19, 20).

3. Dispositif selon la revendication 2, caractérisé en ce que les guides de lumière (11-18) sont placés dans une structure délimitée physiquement de manière qu'une première surface d'extrémité de chaque guide de lumière ou faisceau de guide de lumière se trouve sur l'enveloppe de la structure et joue le rôle d'un élément photorécepteur (1-8) et l'autre surface d'extrémité se trouve en dehors de la structure près des dispositifs de combinaison de lumière (19, 20).

4. Dispositif selon l'une quelconque des revendications précédentes, caractérisé en ce que la lumière tombant sur les éléments photorécepteurs (1, 3, 5, 7 et 2, 4, 6, 8) dans un groupe est combinée par addition des intensités reçues de chaque guide individuel de lumière ou chaque faisceau individuel de groupe de lumière (11, 13, 15, 17 et 12, 14, 16, 18).

Fig. 1

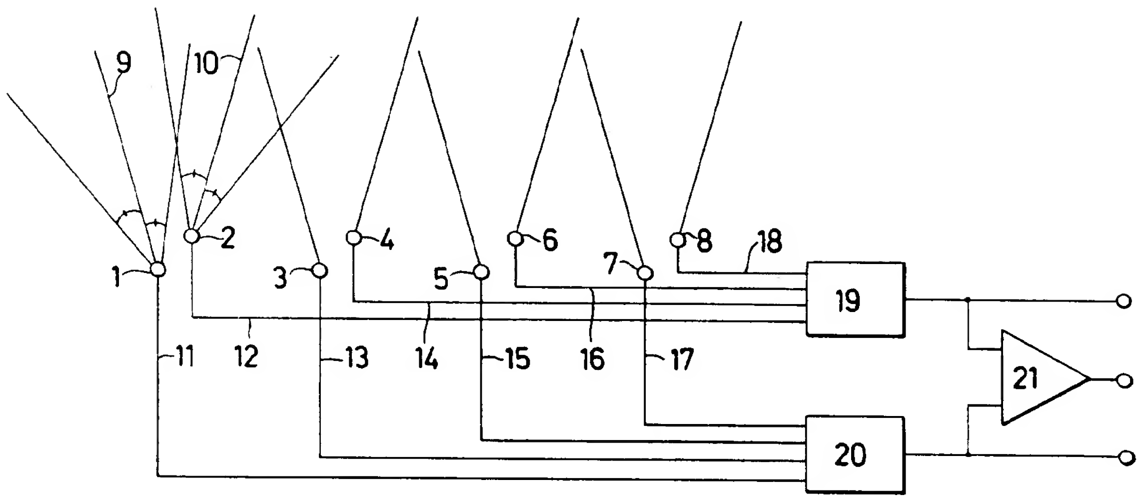
9
10
1
2
3
4
5
6
7
8
18
19
20
21
11
12
13
14
15
16
17

Fig. 2

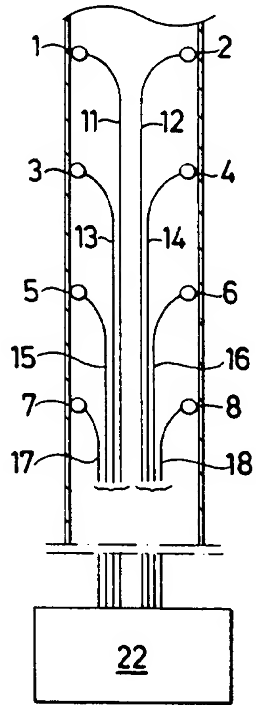
1
2
11
12
3
4
13
14
5
6
15
16
7
8
17
18
22

Fig. 3

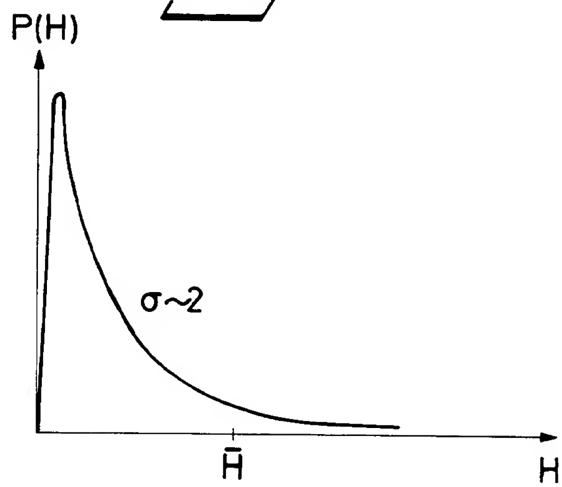

Fig. 4